DESIGN VARIABLES
FOR
CUT SLOPES

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CALTRANS STUDY # D-5-30

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16. ABSTRACT

Two hundred and seventy six cut slopes in various materials throughout the state were inspected as part of this project. Data on the location, orientation, cut slope design, climate, geology and performance are tabulated, compared and discussed. The purpose of these comparisons is to direct future research into the most promising avenues of investigation. Various potentially useful results are present. Criteria for designing cut slopes in disintegrated granitic materials are presented.

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DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS
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September 1973

Research Project
T.L. 632882
D-5-30

Mr. R. J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

DESIGN VARIABLES
FOR
CUT SLOPES

Thomas P. Hoover
Co-Investigator

Ronald Mearns, E. G.
Principal Investigator

Under the Supervision of
Marvin L. McCauley, E. G.

Very truly yours,

JOHN L. BEATON
Laboratory Director

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The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

INTRODUCTION

The development of larger and more powerful earthmoving equipment coupled with improvements and innovations in construction methods have made possible the construction of highway cut slopes of heretofore unimagined magnitude. The technique of designing cut slopes which will remain stable has not kept pace with the improvements in construction equipment and methods. This research was initiated to provide data for a more objective cut slope design technique.

Theoretically, there are a large number of potentially significant variables. This study was undertaken in an attempt to determine if any of the more readily measurable variables correlate with cut slope performance and might therefore prove useful in designing cut slopes.

The general procedure followed in conducting this study consisted of inspecting cuts in all geographic areas of the state. Nearly all cut slopes involved only a single rock type and some cuts in each major rock type were included. Because of this selection process, the sampling is not random and statistical analysis methods cannot be relied upon to provide meaningful cut slope design criteria. The lack of randomness was not considered to be a problem for this study since its basic objective was guidance only in determining the direction for future research.

A total of 276 cut slopes were inspected by experienced engineering geologists on the staff of the Transportation Laboratory. Of these cuts 164 were side hill cuts and 112 were through cuts. The distribution of these cuts is shown in Figure 1 and listed in Table 1. Table 2 lists the designers of the cut slopes included in the study. All cuts included in this study were constructed between 1920 and 1968.

An edge punch data retrieval system was used for storage of all the data. A complete description of the system and its use is included in Appendix A.

The data collection process is described in Appendix B.

Because of the necessity to develop the data retrieval system prior to data collection, certain problems were encountered. It was originally intended to obtain representive samples of the materials for laboratory testing. Variations in the material within a given cut, such as grain size, degree of weathering and mineral composition were found to be much greater than was thought. Because of this condition, the sampling and testing portion of this study was discontinued.

As a result of some early work on this project and experience gained on routine seismic investigations, an apparent correlation between cut slope stability in disintegrated granitic rocks and seismic velocities was noted. To investigate this relationship and to put the findings into effect as soon as possible, research funds were obtained from the California Division of Highways. The results of this correlation study are presented in Appendix C and have proven to be a useful and reliable method of arriving at stable cut slope designs in disintegrated granitic rocks.

TABLE 1

DISTRIBUTION OF CUTS

District	County		No. of Cuts
01			17
	Del Norte	- 7	
	Humboldt	- 5	
	Mendocino	- 5	
02			37
	Lassen	- 6	
	Modoc	- 10	
	Plumas	- 7	
	Shasta	- 4	
	Siskiyou	- 7	
	Tehama	- 3	
03			55
	Butte	- 14	
	El Dorado	- 17	
	Nevada	- 8	
	Placer	- 7	
	Sacramento	- 1	
	Sierra	- 4	
	Yuba	- 4	
04			20
	Alameda	- 5	
	Contra Costa	- 1	
	Marin	- 6	
	Santa Cruz	- 2	
	San Mateo	- 3	
	Sonoma	- 3	
05			32
	Monterey	- 8	
	Santa Barbara	- 13	
	San Benito	- 4	
	San Luis Obispo	- 7	
06	Tulare	- 2	2
07			22
	Los Angeles	- 18	
	Orange	- 3	
	Ventura	- 1	

TABLE 1 (Continued)

DISTRIBUTION OF CUTS

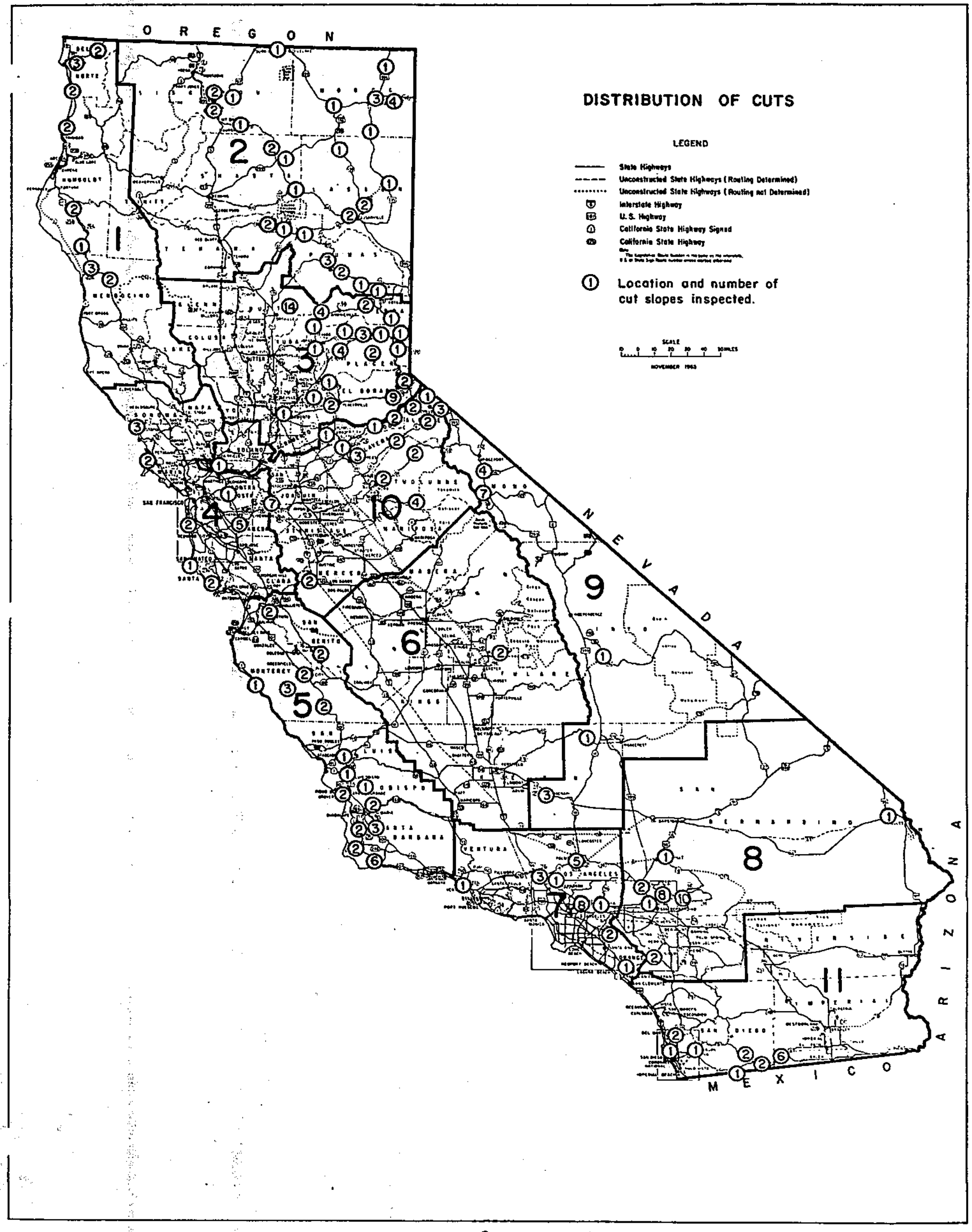
District	County	No. of Cuts
08		25
	Riverside - 2	
	San Bernardino- 23	
09		16
	Inyo - 1	
	Kern - 4	
	Mono - 11	
10		35
	Alameda - 7	
	Alpine - 7	
	Amador - 5	
	Calaveras - 5	
	Merced - 2	
	Solano - 1	
	Tuolumne - 8	
11		15
	Imperial - 6	
	San Diego - 9	
TOTALS 11	43	276

TABLE 2

CUT SLOPE DESIGN AGENCY

Agency	No. of Cuts
California Department of Transportation	
District 01	11
District 02	29
District 03	36
District 04	14
District 05	22
District 06	2
District 07	14
District 08	23
District 09	16
District 10	35
District 11	15
El Dorado County	1
Los Angeles County	8
Mendocino County	3
Monterey County	5
Marin County	3
Riverside County (Prisoners)	2
Sacramento County	1
San Benito County	2
San Luis Obispo County	1
Santa Barbara County	2
Sonoma County	3
Federal Highway Administration	11
California Department of Water Resources	14
Corps. of Engineers	1
Contractors (Not Designed)	2
Totals: 26	276

Figure 1


DISTRIBUTION OF CUTS
LEGEND
Location and number of cut slopes inspected.
OREGON
NEVADA
ARIZONA
MEXICO

CONCLUSIONS

The cut slopes included in this study were not randomly selected, however, the sample is considered of sufficient magnitude and representation of the diversity of rock types and locations on California Highways as to constitute a reliable indicator of relationships which warrant further research.

Further investigation of the factors listed below should define a number of relationships which would be useful in the design of stable cut slopes. The factors are divided into three categories for this discussion.

Geographic information, i.e. rainfall, environment, and topography, appears to be related directly to both slope design and performance.

Geologic information, i.e. lithology, mineralogy, geologic structure, seismic refraction data, and groundwater, also relate directly to both slope design and performance.

Certain relationships between various cut slope descriptors, e.g. cut slope angle, cut slope height, bench data, failures, performance and cut slope age also need to be defined in order to permit the design of stable cut slopes.

IMPLEMENTATION

The data that was collected for this report and the findings contained in Appendix C are being used by the Engineering Geology Group and by some of the Transportation District's to design more stable and economical cut slopes.

Further implementation will require a more comprehensive study of the variables involved. This project has provided the basis for the detailed investigation of the design of highway cuts in intermediate quality rock as well as the relationship of planar features to highway orientation.

RECOMMENDATIONS

To obtain the benefits of an objective approach to cut slope design, the above listed factors are recommended for immediate investigation. Such investigation must be based on a statistically random sample and should be set up to permit data accumulation and analysis by computer. The random sample is necessary to assure the widest possible applicability of the resultant design criteria.

It is also recommended that multifactor analysis of the existing data be performed to determine if similar analysis of the statistically significant data recommended above is warranted. The potential for this type analysis should be incorporated into the computer program at the time of its development.

It is recommended that the angular relationships between the geologic structural features present and the cut slope face be investigated. Such features are a significant factor in slope stability and there is insufficient data available to permit their consideration in cut slope design.

The problems experienced with the edge punched data retrieval system on the project were significant in magnitude and, as a result, it is recommended that for either large numbers of variables or for large data sets that only computer storage and analysis be considered.

ANALYSIS AND RESULTS

The data gathered for this project are summarized in Tables 3 through 13. These tables are self explanatory and describe the data available for the analyses described below. The total number of cuts in some tables exceeds 276, the number of cuts inspected. This occurs because some cuts are included in more than one category.

TABLE 3

CUT SLOPE ANGLE

Angle	No. of Cuts
1/8:1	2
1/4:1	11
1/2:1	52
3/4:1	68
1:1	88
1 1/4:1	9
1 1/2:1	45
2:1	15
3:1	3
4:1	1

TABLE 4

CUT SLOPE HEIGHT

Height Range (ft.)	No. of Cuts
39 or less	32
40 through 80	121
81 through 120	52
Greater than 120	71

TABLE 5

BENCH DATA

No. of Benches	Height Between Benches	No. of Cuts
None	--	185
2 or Less	49 ft. or less	19
	50 ft. or more	6
3 or More	49 ft. or less	33
	50 ft. or more	33

TABLE 6

SPECIAL TREATMENTS

Type	No. of Cuts
Widening at Grade	68
Plantings	22
Horizontal Drains	10
Fences	7
Slope Rounding	4
Strut Fills	2
Presplitting	1
Underdrains	1

TABLE 7

FAILURES

Type	No. of Cuts
Ravelling	125
Rockfall	78
Erosion	63
Surface Slides	48
Deep Slides	3
Other (Sloughing, etc.)	33
None	20

TABLE 8

ENVIRONMENT

Type	No. of Cuts
Desert	7
Coast	30
Low Mountains	132
High Mountains	107

TABLE 9

RAINFALL

Amount (Inches)	No. of Cuts
Less than 15	72
15 through 50	163
Greater than 50	41

TABLE 10

GEOLOGIC DATA

Type	No. of Cuts
Joints	145
Faults	78
Foliations	50
None of These	110
Clay Minerals Present	167
Weathering	
Fresh	28
Slightly Weathered	53
Moderately Weathered	147
Weathered	85
Very Weathered	83
Seismic Velocity Obtained	38
Groundwater Data	
Watertable	19
Fracture Water	11
Springs and Seeps	50
Unknown	257

TABLE 11

LITHOLOGY

Rock Type	No. of Cuts
Granite	67
Diorite	19
Ultrabasic	2
Gabbro	1
Andesite	17
Volcanic Mudflow	11
Basalt	8
Agglomerate	7
Tuff	3
Rhyolite	2
Greenstone	18
Schist	6
Serpentine	6
Slate	3
Metagranitic	3
Metavolcanic	2
Meta Sandstone	1
Sandstone	29
Shale	20
Unconsolidated Sediments	18
Moraine	12
Conglomerate	7
Siltstone	6
Terrace	6
Talus	2

TABLE 12

NATURAL SLOPES

Slope Angle (Degrees)	Slope Height (Feet)	No. of Cuts
Less than 32	Less than 100	46
	100 or greater	103
32 or Greater	Less than 100	30
	100 or greater	88
Unknown	- - - - - - - -	9

TABLE 13

CUT SLOPE PERFORMANCE

Performance	No. of Cuts
Very Good	61
Good	133
Marginal	47
Unsatisfactory	35

The following analysis is expressed only in general terms. The conclusions expressed are observations based on this set of data. They are presented to indicate the direction for future studies and not necessarily as guidelines for cut slope design. Only the observations which are considered significant or which suggest possible useful correlations are included in the following discussion.

The following observations are all based on simple two factor comparisons because the analysis of more than two factors was too time consuming and difficult to obtain with the edge punch system. Multifactor analysis should be explored in future projects as additional useful data would probably be developed.

The use of the term "Failures" as one of the cut slope descriptors requires some explanation. "Failures" would more properly be termed "Problems" as they refer to any of a group of conditions which contribute to maintenance problems and costs, result in hazards or pollution, or which create unsightly conditions. These "Failures" are not to be confused with cut slope perfomance. Cut slope performance could have been judged very good and yet the cut slope could exhibit one or more of the "Failures".

Soil creep was one of the categories of "Failures" included when the data collection system was established. This category was not used by any inspector to describe any cut. The absence of this type of failure probably results from the removal of soil in constructing the cut slope and, because the cut slopes are generally steeper than natural slopes, they exhibit a rate of failure too rapid to be considered as soil creep.

In attempting to perform the following analyses certain comparisons could only be made with considerable manual tabulation. Limitations in time and funds precluded completing many of these analyses. The most promising of these comparisons should be completed as part of future research projects. Those comparisons which show the most promise and for which further study is recommended will be preceeded by an asterisk (*).

The first analyses consisted of comparing each of the variables listed in Appendix A with each of the descriptors in the same listing. It was hoped that suspected relationships could be substantiated or that perhaps new useful relationships could be discovered. Only those comparisons which were believed potentially useful were undertaken as described as follows.

Variables

Rainfall

The cut slopes were originally grouped into three rainfall categories: less than 10 inches; 10-20 inches; and greater than 20 inches. These groupings were arbitrarily selected and during the analysis, it was decided to change the different arbitrary groupings: less than 15 inches; 15-50 inches; and greater than 50 inches. These groupings in general correspond to main geographic areas of California: the desert and portions of Southern California; the central valley and much of the coastline; and the north coast and high mountains.

The data used for this portion of the project was based on the most recent annual report from the U. S. Weather Service reporting station nearest to the cut slope. This distance is sometimes considerable and errors undoubtedly exist as a result. It should also be pointed out that this information is based on annual totals and no evaluation of rainfall intensities is included.

The data for comparing rainfall to the cut slope descriptors are included in Tables 14 through 20.

TABLE 14

RAINFALL VS CUT SLOPE ANGLE

	Cut Slope Angle				
Rainfall	≥ 1/2:1	3/4:1	1:1	1 1/2:1	≤ 2:1
<15	12	11	23	15	11
15-50	38	43	47	30	5
>50	11	8	17	4	1

TABLE 15

RAINFALL VS CUT SLOPE HEIGHT

Rainfall	Cut Slope Height <40	40-80	81-120	> 120
<15	9	21	18	24
15-50	19	77	28	39
>50	4	23	6	8

TABLE 16

RAINFALL VS CUT TYPE

Rainfall	Cut Type Through	Sidehill
<15	40	32
15-50	63	100
>50	9	32

TABLE 17

RAINFALL VS NO. OF BENCHES

Rainfall	No. of Benches ≤2	≥3	0
<15	19	4	49
15-50	42	19	102
>50	5	2	34

TABLE 18

RAINFALL VS BENCH HEIGHT

Rainfall	Bench Height ≤49	Bench Height ≥50
<15	10	13
15-50	40	21
>50	1	6

TABLE 19

RAINFALL VS FAILURES

Rainfall	Erosion	Ravelling	Rockfall	Surface Slides	Deep Slides	Others	None
<15	14	29	27	12	0	5	6
15-50	38	77	36	32	2	22	13
>50	11	19	15	4	1	6	1

TABLE 20

RAINFALL VS PERFORMANCE

Rainfall	Very Good	Good	Marginal	Unsatisfactory
<15	21	31	10	10
15-50	31	78	32	22
>50	9	24	5	5

*The comparison between rainfall and cut slope angle discloses the disproportionate number of flat slope angles in the less than 15 inches of rainfall areas.

*There is an extremely high percentage of sidehill type cuts in the greater than 50 inches of rainfall areas and there appears to be a disproportionate percentage in the 40 to 80 foot heights. It is probable that roadway design criteria and natural slope conditions are related to these observations.

Erosion was found to vary directly with rainfall while ravelling appears to occur independently of the amount of rainfall. More cut slopes in the areas of high rainfall exhibit failures than in the lower rainfall areas. These observations confirm previous opinions and can serve as guides in considering cut slope designs.

Environment

This variable was arbitrarily divided into four categories: Desert; Coast; Low Mountains; and High Mountains. These categories do not relate to geographic areas and all except the Coast are found throughout the state. The purpose for including this variable was to incorporate such factors as humidity, temperature, wind, vegetation, animals, etc., into the study. It is obvious that the categories selected are limited in their capability to do this and subsequent analysis of the data confirmed this statement. Future studies of this type should have a more sophisticated system of describing an environment.

Tables 21 through 27 present the data on environment.

TABLE 21

ENVIRONMENT VS CUT SLOPE ANGLE

	Cut Slope Angle				
Environment	≥1/2:1	3/4:1	1:1	1 1/2:1	≤2:1
Desert	2	2	1	1	1
Coast	8	6	7	6	3
Low Mountains	31	31	34	24	12
High Mountains	20	23	45	18	1

TABLE 22

ENVIRONMENT VS CUT SLOPE HEIGHT

	Cut Slope Height			
Environment	<40	40-80	81-120	>120
Desert	4	2	1	0
Coast	6	10	3	11
Low Mountains	7	49	27	49
High Mountains	15	60	21	11

TABLE 23

ENVIRONMENT VS CUT TYPE

	Cut Type	
Environment	Through	Sidehill
Desert	4	3
Coast	6	24
Low Mountains	57	75
High Mountains	45	62

TABLE 24

ENVIRONMENT

	No. of Benches		
Environment	≤2	≥3	0
Desert	0	1	6
Coast	6	4	20
Low Mountains	41	17	74
High Mountains	19	3	85

TABLE 25

ENVIRONMENT VS BENCH HEIGHT

Environment	Bench Height ≤ 49	Bench Height ≥ 50
Desert	1	0
Coast	1	9
Low Mountains	37	21
High Mountains	12	10

TABLE 26

ENVIRONMENT VS FAILURES

Environment	Erosion	Ravelling	Rockfall	Surface Slides	Deep Slides	Other	None
	Failures						
Desert	2	2	3	1	0	0	1
Coast	15	10	1	5	1	3	3
Low Mountains	18	69	22	28	2	11	15
High Mountains	28	44	52	14	0	19	1

TABLE 27

ENVIRONMENT VS PERFORMANCE

Environment	Very Good	Good	Marginal	Unsatisfactory
	Performance			
Desert	0	5	1	1
Coast	4	19	5	2
Low Mountains	37	54	23	18
High Mountains	20	55	18	14

The distribution of each cut slope angle in each environment is remarkably similar with two exceptions: The use of 1:1 cut slopes in High Mountains was disproportionately high and in Low Mountains was disproportionately low; and the use of 2:1 cut slopes in Low Mountains was extremely high and in High Mountains was extremely low.

Cut slopes in the Desert had low heights.

A majority of cut slopes in High Mountains were in the 40-80 foot height group.

An extremely high percentage of cut slopes in the Coast category were sidehill cuts.

Most cuts were unbenched but extremely high percentages of both the Desert and High Mountains categories were unbenched.

Half of the cuts in the Coast category experienced erosion.

Most Erosion, Ravelling and Rockfall, occurs in either High or Low Mountains.

*Only one percent of the High Mountain cut slopes exhibited no failures. The other environments were 10 to 15% without failures.

Lithology

Although detailed lithologic data was gathered, it was decided to analyze the data on only the four major categories of Igneous Intrusive, Igneous Extrusive, Metamorphic, and Sedimentary. The data for this analysis is contained in Tables 28 through 34.

TABLE 28

LITHOLOGY VS CUT SLOPE ANGLE

	Cut Slope Angle				
Lithology	≥1/2:1	3/4:1	1:1	1 1/2:1	≤2:1
Igneous Intrusive	36	26	17	8	2
Igneous Extrusive	8	7	23	10	0
Metamorphic	8	10	15	6	0
Sedimentary	9	19	32	25	15

TABLE 29

LITHOLOGY VS CUT SLOPE HEIGHT

Lithology	Cut Slope Height <40	40-80	81-120	>120
Igneous Intrusive	14	40	25	10
Igneous Extrusive	11	26	7	4
Metamorphic	1	14	7	17
Sedimentary	6	41	13	40

TABLE 30

LITHOLOGY VS CUT TYPE

Lithology	Cut Type Through	Sidehill
Igneous Intrusive	36	53
Igneous Extrusive	27	21
Metamorphic	17	22
Sedimentary	32	68

TABLE 31

LITHOLOGY VS NO. OF BENCHES

Lithology	No. of Benches ≤2	≥3	0
Igneous Intrusive	17	3	69
Igneous Extrusive	7	0	41
Metamorphic	14	11	14
Sedimentary	28	11	61

TABLE 32

LITHOLOGY VS BENCH HEIGHT

Lithology	Bench Height ≤49	Bench Height ≥50
Igneous Intrusive	11	9
Igneous Extrusive	4	3
Metamorphic	18	7
Sedimentary	18	21

TABLE 33

LITHOLOGY VS FAILURES

Lithology	Failures: Erosion	Ravelling	Rockfall	Surface Slides	Deep Slides	Other	None
Igneous Intrusive	24	33	32	18	0	12	7
Igneous Extrusive	7	19	28	3	0	9	1
Metamorphic	2	21	4	12	1	5	3
Sedimentary	30	52	14	15	2	7	9

TABLE 34

LITHOLOGY VS PERFORMANCE

Lithology	Performance: Very Good	Good	Marginal	Unsatisfactory
Igneous Intrusive	20	35	17	17
Igneous Extrusive	12	27	5	4
Metamorphic	3	23	8	5
Sedimentary	25	49	17	9

*Most cut slopes in Igneous Intrusive rocks are 3/4:1 or steeper. Most cut slopes in Igneous Extrusive and Metamorphic rocks are 1:1 or steeper. Cuts in Sedimentary rock are found at all angles included in this study. Nearly all 2:1 or flatter slopes were encountered in Sedimentary rocks.

An unusually high percentage of Igneous Extrusive rocks are through cuts, and an unusually high percentage of cuts in Sedimentary rocks are sidehill cuts.

An extremely high percentage of cuts in Igneous Extrusive rocks are unbenched. An unusually high percentage of cuts in Metamorphic rocks are benched, and the vertical spacing between benches is primarily less than 50 feet.

*Cuts in Igneous Extrusive rocks exhibit the lowest percentage without some Failures. Sedimentary and Igneous Intrusive rocks are more erodible than the Metamorphic and Igneous Extrusive. Most of the Failures other than erosion for all types of rock are Ravelling and Rockfall.

*Sedimentary and Igneous Intrusive rocks were encountered in 75% of the cuts judged unsatisfactory. This observation may be related to the one above.

Seismic Refraction Data

In developing this project, a knowledge of seismic velocities was included because it was desired to determine if more effective design of cut slopes could be obtained when seismic velocities were used. Insufficient data was gathered to make such a determination. The bulk of the seismic data was obtained in Igneous Intrusive rocks, and additional analysis of this data is contained in Appendix C. Data for this analysis is contained in Tables 35 through 41.

TABLE 35

SEISMIC REFRACTION DATA VS CUT SLOPE ANGLE

	Cut Slope Angle				
Seismic Data	$\geq$1/2:1	3/4:1	1:1	1 1/2:1	$\leq$2:1
Yes	12	12	6	7	1
No	49	50	81	42	16

TABLE 36

SEISMIC REFRACTION DATA VS CUT SLOPE HEIGHT

Seismic Data	Cut Slope Height <40	40-80	81-120	>120
Yes	8	20	6	4
No	24	101	46	67

TABLE 37

SEISMIC REFRACTION DATA VS CUT TYPE

Seismic Data	Cut Type Through	Sidehill
Yes	12	26
No	100	138

TABLE 38

SEISMIC REFRACTION DATA VS NO. OF BENCHES

Seismic Data	No. of Benches ≤ 2	≥ 3	0
Yes	7	2	29
No	59	23	156

TABLE 39

SEISMIC REFRACTION DATA VS BENCH HEIGHT

Seismic Data	Bench Height ≤ 49	≥ 50
Yes	3	6
No	48	34

TABLE 40

SEISMIC REFRACTION DATA VS FAILURES

Seismic Data	Failures: Erosion	Ravelling	Rockfall	Surface Slide	Deep Slide	Other	None
Yes	20	17	3	8	1	3	3
No	43	108	75	40	2	30	17

TABLE 41

SEISMIC REFRACTION DATA VS PERFORMANCE

Seismic Data	Performance: Very Good	Good	Marginal	Unsatisfactory
Yes	8	14	12	4
No	53	119	35	31

*A higher percentage of cut slopes are 3/4:1 or steeper when designed using seismic velocities than when designed without them.

*Those cuts designed without seismic data exhibited substantially higher percentages of every type of Failure included in this study. At the same time these cuts were judged to have performed better than the cuts designed with seismic data.

Geologic Structure

Joints, Faults, and Foliations or the lack of any of these was investigated to determine their relationship to cut slope design. Tables 42 through 48 present the data used in determining these relationships.

TABLE 42

GEOLOGIC STRUCTURE VS CUT SLOPE ANGLE

	Cut Slope Angle				
Geologic Structure	≥1/2:1	3/4:1	1:1	1 1/2:1	≤2:1
Joints	56	40	36	12	1
Faults	30	25	18	5	0
Foliations	12	18	14	6	0
None	3	19	38	34	16

TABLE 43

GEOLOGIC STRUCTURE VS CUT SLOPE HEIGHT

	Cut Slope Height			
Geologic Structure	<40	40-80	81-120	>120
Joints	17	64	34	30
Faults	9	23	22	24
Foliations	1	15	17	17
None	13	47	14	36

TABLE 44

GEOLOGIC STRUCTURE VS CUT TYPE

Geologic Structure	Cut Type	
	Through	Sidehill
Joints	53	92
Faults	29	49
Foliations	19	31
None	47	63

TABLE 45

GEOLOGIC STRUCTURE VS NO. OF BENCHES

Geologic Structure	No. of Benches		
	≤2	≥3	0
Joints	31	16	98
Faults	18	15	45
Foliations	19	11	20
None	30	8	72

TABLE 46

GEOLOGIC STRUCTURE VS BENCH HEIGHT

Geologic Structure	Bench Height	
	≤49	≥50
Joints	27	20
Faults	20	13
Foliations	24	6
None	21	17

TABLE 47

GEOLOGIC STRUCTURE VS FAILURES

Geologic Structure	Erosion	Ravelling	Rockfall	Surface Slides	Deep Slides	Others	None
	Failures						
Joints	15	67	53	25	2	11	12
Faults	8	38	23	20	1	6	8
Foliations	4	26	7	12	1	4	5
None	45	47	20	19	0	19	5

TABLE 48

GEOLOGIC STRUCTURE VS PERFORMANCE

Geologic Structure	Very Good	Good	Marginal	Unsatisfactory
	Performance			
Joints	26	78	22	19
Faults	8	40	18	12
Foliations	9	25	9	7
None	30	46	21	13

It appears that the absence of structural features is related to the flatter cut slopes, and conversely steeper cut slopes are found in those cuts exhibiting the geologic features. This is probably due to the fact that the materials requiring a flat slope for stability are too weathered to permit observations of geologic structure, while the less weathered rock which will stand at the steep angles will permit observation of structure.

The above explanation also accounts for the observation that the absence of structure is related to the occurrence of Erosion, while Rockfall occurs in those cuts with Geologic Structure.

*The presence of Faults in the cut slope material appears to correlate with poorer performance evaluations.

Natural Slope Data

The angle and height of natural slopes in the area of each cut was recorded to evaluate their relationship to cut slope design.

The Natural Slope Angle was originally divided into two groups, less than 45° and 45° or greater. For purposes of analysis, these groups were changed to less than 32° and 32° or greater, because of an apparent gap in the distribution of natural slope angles.

The Natural Slope Height was arbitrarily divided into two groups less than 100 feet and 100 feet or greater. These groups were used to complete the analysis.

Tables 49 through 55 contain the data used in this analysis.

TABLE 49

NATURAL SLOPE DATA VS CUT SLOPE ANGLE

	Cut Slope Angle				
Natural Slope Angle	≥1/2:1	3/4:1	1:1	1 1/2:1	≤2:1
<32	17	26	51	40	15
≥32	39	34	35	9	1
None	5	2	1	0	1
Natural Slope Height					
<100	14	17	30	10	5
≥100	42	43	56	39	11
None	5	2	1	0	1

TABLE 50

NATURAL SLOPE DATA VS CUT SLOPE HEIGHT

Natural Slope Angle	Cut Slope Height < 40	40-80	81-120	> 120
< 32	18	68	25	38
≥ 32	10	48	27	33
None	4	5	0	0
Natural Slope Height				
< 100	20	49	3	4
≥ 100	8	67	49	67
None	4	5	0	0

TABLE 51

NATURAL SLOPE DATA VS CUT TYPE

Natural Slope Angle	Cut Type Through	Sidehill
<32	75	74
≥32	33	85
None	4	5
Natural Slope Height		
<100	39	37
≥100	69	122
None	4	5

TABLE 52

NATURAL SLOPE DATA VS NO. OF BENCHES

Natural Slope Angle	No. of Benches ≤2	≥3	0
<32	30	11	108
≥32	35	14	69
None	1	0	8
Natural Slope Height			
<100	9	2	65
≥100	56	23	112
None	1	0	8

TABLE 53

NATURAL SLOPE DATA VS BENCH HEIGHT

Natural Slope Angle	Bench Height ≤49	≥50
<32	23	18
≥32	27	22
None	1	0
Natural Slope Height		
<100	9	2
≥100	41	38
None	1	0

TABLE 54

NATURAL SLOPE DATA VS FAILURES

Natural Slope Angle	Erosion	Ravelling	Rockfall	Surface Slides	Deep Slides	Other	None
	Failures						
<32	40	64	42	28	1	25	10
≥32	21	59	33	20	2	8	8
None	2	2	3	0	0	0	2
Natural Slope Height							
<100	22	34	24	4	1	13	5
≥100	39	89	51	44	2	20	13
None	2	2	3	0	0	0	2

TABLE 55

NATURAL SLOPE DATA VS PERFORMANCE

Natural Slope Angle	Very Good	Good	Marginal	Unsatisfactory
	Performance			
<32	42	66	25	16
≥32	15	64	22	17
None	4	3	0	2
Natural Slope Height				
<100	20	42	9	5
≥100	37	88	38	28
None	4	3	0	2

*Although Natural Slope Height showed no relationship with cut slope angle, the Natural Slope Angle did. The flatter cut slopes were in areas of flatter natural slopes, and the steeper cut slopes were in areas of steeper natural slopes.

Groundwater

The presence or absence of water in a hill is definitely a factor in determining stability. In this study, an attempt was made to identify this relationship by indicating the presence of water. The categories used are Unknown, Springs and Seeps, Fracture Water and Water Table. The data collected for this analysis is presented in Tables 56 through 62. The category titled Unknown refers only to Water Table.

TABLE 56

GROUNDWATER VS CUT SLOPE ANGLE

Groundwater	Cut Slope Angle ≥1/2:1	3/4:1	1:1	1 1/2:1	≤2:1
Unknown	59	50	83	48	17
Springs & Seeps	10	9	18	9	4
Fracture Water	5	2	4	0	0
Water Table	2	12	4	1	0

TABLE 57

GROUNDWATER VS CUT SLOPE HEIGHT

Groundwater	Cut Slope Height <40	40-80	81-120	>120
Unknown	32	117	48	60
Springs & Seeps	4	20	9	17
Fracture Water	2	4	0	5
Water Table	0	4	4	11

TABLE 58

GROUNDWATER VS CUT TYPE

Groundwater	Cut Type: Through	Cut Type: Sidehill
Unknown	103	154
Springs & Seeps	17	33
Fracture Water	4	7
Water Table	9	10

TABLE 59

GROUNDWATER VS NO. OF BENCHES

Groundwater	No. of Benches: ≤2	≥3	0
Unknown	60	19	178
Springs & Seeps	11	6	33
Fracture Water	3	2	6
Water Table	6	6	7

TABLE 60

GROUNDWATER VS BENCH HEIGHT

Groundwater	Bench Height: ≤49	≥50
Unknown	40	39
Springs & Seeps	10	7
Fracture Water	1	4
Water Table	11	1

TABLE 61

GROUNDWATER VS FAILURES

Groundwater	Failures: Erosion	Ravelling	Rockfall	Surface Slide	Deep Slide	Other	None
Unknown	62	110	77	42	3	33	20
Springs & Seeps	10	17	15	12	2	7	4
Fracture Water	2	5	2	2	0	0	1
Water Table	1	15	1	6	0	0	0

TABLE 62

GROUNDWATER VS PERFORMANCE

Groundwater	Performance: Very Good	Good	Marginal	Unsatisfactory
Unknown	60	120	43	34
Springs & Seeps	9	26	6	9
Fracture Water	2	7	2	0
Water Table	1	13	4	1

It was difficult to obtain information on groundwater and only a few cut slopes are included in this portion of the study. Fracture Water and Water Table data is especially limited. The following observations are definitely limited by this factor.

*Fracture Water was observed only in 1:1 and steeper slopes, probably because the steep slopes are constructed in rock, a material which can be and usually is fractured. Springs and seeps were observed in all cut slope angles, while Water Tables were found mostly in the steep cut slopes.

Water Table data was available in the higher cuts. Water Table data was also found to correspond to an unusually high use of benching in cut slope design.

*Those cut slopes in which Fracture Water was detected appear to have received better performance evaluations.

Clay

Because the presence of clay is a factor in stability, its presence was included in the study. Any clearly identifiable clay mineral whether in the rock mass or in seams, fractures or faults was included. No tests were performed on most of these clays so they cannot be identified as to type. Tables 63 through 69 contain the data used in this analysis.

TABLE 63

CLAY VS CUT SLOPE ANGLE

	Cut Slope Angle				
Clay	≥1/2:1	3/4:1	1:1	1 1/2:1	≤2:1
Yes	25	33	61	36	12
No	36	29	26	13	5

TABLE 64

CLAY VS CUT SLOPE HEIGHT

Clay	Cut Slope Height <40	40-80	81-120	>120
Yes	19	78	31	39
No	13	43	21	32

TABLE 65

CLAY VS CUT TYPE

Clay	Cut Type Through	Sidehill
Yes	71	96
No	41	68

TABLE 66

CLAY VS NO. OF BENCHES

Clay	No. of Benches ≤2	≥3	0
Yes	37	11	119
No	29	14	66

TABLE 67

CLAY VS. BENCH HEIGHT

Clay	Bench Height ≤49	Bench Height ≥50
Yes	28	20
No	23	20

TABLE 68

CLAY VS FAILURES

Clay	Failures: Erosion	Ravelling	Rockfall	Surface Slide	Deep Slide	Other	None
Yes	49	76	45	31	0	30	9
No	14	49	33	17	3	3	11

TABLE 69

CLAY VS PERFORMANCE

Clay	Performance: Very Good	Good	Marginal	Unsatisfactory
Yes	48	73	29	17
No	13	60	18	18

The study of disintegrated granitic rocks reported in Appendix C includes some information on the presence of clay.

*Clay was found more often in the flatter cut slopes and less often in the steeper slopes. This information proved useful in designing slopes in disintegrated granitic rocks. Perhaps this relationship exists for other rock types.

Weathering

Weathering is a geologic term which includes a number of variables such as type of material, climate, and water. The categories used for this analysis are Fresh, Slightly Weathered, Moderately Weathered, Weathered and Very Weathered. The data for this analysis is presented in Tables 70 through 76.

The weathering category titles are common geologic terms and their application was left to the discretion of the inspecting geologist. Some variations are certain to exist and in future studies, a single inspector should be used or precise objective definitions should be developed.

TABLE 70

WEATHERING VS CUT SLOPE ANGLE

	Cut Slope Angle				
Weathering	≥1/2:1	3/4:1	1:1	1 1/2:1	≤2:1
Fresh	9	11	6	1	1
Slightly Weathered	24	10	10	7	2
Moderately Weathered	21	30	50	34	12
Weathered	22	18	31	12	2
Very Weathered	21	23	24	13	2

TABLE 71

WEATHERING VS CUT SLOPE HEIGHT

	Cut Slope Height			
Weathering	<40	40-80	81-120	>120
Fresh	6	11	8	3
Slightly Weathered	7	18	11	17
Moderately Weathered	13	54	34	46
Weathered	12	40	14	19
Very Weathered	9	39	17	18

TABLE 72

WEATHERING VS CUT TYPE

Weathering	Cut Type: Through	Cut Type: Sidehill
Fresh	12	16
Slightly Weathered	23	30
Moderately Weathered	66	81
Weathered	36	49
Very Weathered	30	53

TABLE 73

WEATHERING VS NO. OF BENCHES

Weathering	No. of Benches: ≤2	≥3	0
Fresh	5	2	21
Slightly Weathered	9	6	38
Moderately Weathered	38	17	92
Weathered	18	11	56
Very Weathered	24	12	47

TABLE 74

WEATHERING VS BENCH HEIGHT

Weathering	Bench Height: ≤49	≥50
Fresh	1	6
Slightly Weathered	4	11
Moderately Weathered	29	26
Weathered	18	11
Very Weathered	28	8

TABLE 75

WEATHERING VS FAILURES

Weathering	Erosion	Ravelling	Rockfall	Surface Slide	Deep Slide	Other	None
	Failures						
Fresh	2	9	17	4	0	2	2
Slightly Weathered	7	19	29	9	1	2	4
Moderately Weathered	32	68	46	20	0	17	12
Weathered	18	39	20	21	3	14	4
Very Weathered	26	40	8	24	1	12	5

TABLE 76

WEATHERING VS PERFORMANCE

Weathering	Very Good	Good	Marginal	Unsatisfactory
	Performance			
Fresh	2	12	10	4
Slightly Weathered	3	31	8	11
Moderately Weathered	39	73	18	17
Weathered	12	43	13	17
Very Weathered	14	40	17	12

One problem with this analysis is the impossibility of applying a single word describing weathering to all materials exposed in the cut face. Obviously the soil layer is more weathered than the material in the heart of the cut. These comparisons do not offer results of sufficient meaning to justify further research at this time.

Erosion and Ravelling are characteristic of the more weathered materials. This was anticipated.

DESCRIPTORS

Comparisons between certain cut slope descriptors were made in an attempt to define interrelationships that might affect cut slope design. These comparisons are described below.

Cut Slope Angle

The Cut Slope Angles were divided into five groups: 1/2:1 and steeper; 3/4:1, 1:1; 1 1/2:1; and 2:1 and flatter. Tables 77 through 83 summarize the data used in these comparisons.

TABLE 77

CUT SLOPE ANGLE VS CUT SLOPE HEIGHT

Cut Slope Angle	Cut Slope Height <40	40-80	81-120	>120
≥1/2:1	11	30	15	5
3/4:1	5	21	19	17
1:1	7	52	10	18
1 1/2:1	6	13	6	24
≤2:1	3	5	2	7

TABLE 78

CUT SLOPE ANGLE VS CUT TYPE

Cut Slope Angle	Cut Type Through	Sidehill
≥1/2:1	15	46
3/4:1	27	35
1:1	45	42
1 1/2:1	18	31
≤2:1	7	10

TABLE 79

CUT SLOPE ANGLE VS NO. OF BENCHES

Cut Slope Angle	No. of Benches ≤2	≥3	0
≥1/2:1	12	3	46
3/4:1	20	6	36
1:1	21	8	58
1 1/2:1	12	8	29
≤2:1	1	0	16

TABLE 80

CUT SLOPE ANGLE VS BENCH HEIGHT

Cut Slope Angle	Bench Height ≤49	≥50
≥1/2:1	9	6
3/4:1	15	11
1:1	19	10
1 1/2:1	8	12
≤2:1	0	1

TABLE 81

CUT SLOPE ANGLE VS FAILURES

Cut Slope Angle	Failures: Erosion	Ravelling	Rockfall	Surface Slide	Deep Slide	Other	None
≥1/2:1	6	27	22	11	0	4	4
3/4:1	8	37	18	6	1	6	3
1:1	15	44	30	14	1	16	4
1 1/2:1	27	14	8	13	1	7	4
≤2:1	7	3	0	4	0	0	5

TABLE 82

CUT SLOPE ANGLE VS PERFORMANCE

Cut Slope Angle	Performance			
	Very Good	Good	Marginal	Unsatisfactory
≥1/2:1	15	22	10	14
3/4:1	11	30	17	4
1:1	13	56	9	9
1 1/2:1	15	20	10	4
≤2:1	7	5	1	4

TABLE 83

CUT SLOPE ANGLE VS CUT SLOPE AGE

Cut Slope Angle	Cut Slope Age		
	<5	5-15	>15
≥1/2:1	20	17	24
3/4:1	20	13	29
1:1	24	32	31
1 1/2:1	17	24	8
≤2:1	12	5	0

Generally, the steep slopes are lower in height, are sidehill cuts, and are unbenched.

*Generally, the failure groups defined in this study are most apparent in the 1:1 and the 1 1/2:1 cut slopes. It appears that these intermediate cut slope angles are more problem prone than the others. Especially significant is the high percentage of 1 1/2:1 cut slopes that exhibit erosion. A detailed analysis of the relationship between cut slope angle and erosion is strongly recommended.

The very steep and the very flat Cut Slope Angles are disproportionately high in the unsatisfactory performance category. Apparently, the use of extreme Cut Slope Angles occurs only under abnormal conditions that decrease the chance of successful cut slope performance.

It was observed that there is a general trend in Cut Slope Angle versus Cut Slope Age. The oldest cut slopes are the steepest. This may reflect a long term shift in cut slope design philosophy.

Cut Slope Height

Cut slope heights were divided into four arbitrary categories: less than 40 feet; 40 to 80 feet; 81 to 120 feet; and greater than 120 feet. Tables 84 through 89 contain the data used for this analysis.

TABLE 84

CUT SLOPE HEIGHT VS CUT TYPE

	Cut Type	
Cut Slope Height	Through	Sidehill
<40	17	15
40-80	52	69
81-120	20	32
>120	23	48

TABLE 85

CUT SLOPE HEIGHT VS NO. OF BENCHES

Cut Slope Height	No. of Benches ≤2	≥3	0
<40	1	0	31
40-80	19	0	102
81-120	20	2	30
>120	26	23	22

TABLE 86

CUT SLOPE HEIGHT VS BENCH HEIGHT

Cut Slope Height	Bench Height ≤49	≥50
<40	1	0
40-80	15	4
81-120	15	7
>120	20	29

TABLE 87

CUT SLOPE HEIGHT VS FAILURES

Cut Slope Height	Erosion	Ravelling	Rockfall	Surface Slide	Deep Slide	Other	None
	Failures						
<40	12	5	12	2	0	3	6
40-80	27	64	38	13	2	16	5
81-120	7	24	21	14	0	7	1
>120	17	32	7	19	1	7	8

TABLE 88

CUT SLOPE HEIGHT VS PERFORMANCE

Cut Slope Height	Very Good	Good	Marginal	Unsatisfactory
	Performance			
<40	6	19	4	3
40-80	28	59	20	14
81-120	11	18	10	13
>120	16	37	13	5

TABLE 89

CUT SLOPE HEIGHT VS CUT SLOPE AGE

Cut Slope Height	<5	5-15	>15
	Cut Slope Age		
<40	6	12	14
40-80	33	38	50
81-120	19	16	17
>120	35	25	11

*An unusually high percentage of the higher cut slopes are benched and the larger bench spacings were used.

*The 81-120 ft. height cut slopes were judged to have unsatisfactory performance a disproportionate percentage of the time.

*In line with previous observations, it was found that the oldest cut slopes were low while the youngest cut slopes were high. A historical trend such as this, should be evaluated to determine its cause and to assure the necessity of the change.

Cut Type

Two types of cuts, through and sidehill, were investigated in this study. Tables 90 and 91 present the data for these analyses.

TABLE 90

CUT TYPE VS PERFORMANCE

Cut Type	Performance			
	Very Good	Good	Marginal	Unsatisfactory
Through	26	54	15	17
Sidehill	35	79	32	18

TABLE 91

CUT TYPE VS CUT SLOPE AGE

Cut Type	Cut Slope Age		
	<5	5-15	>15
Through	34	47	31
Sidehill	59	44	61

A disproportionately high percentage of sidehill cuts received marginal performance evaluations. Also a disproportionately low percentage of sidehill cuts were found to be of intermediate age.

Benches

In order to analyze bench data, the cut slopes were divided into groups as follows:

No Benches
Two or One Bench
Three or more Benches

A further division was made by difference in elevation between benches as follows:

Less than 50 Feet
50 Feet or Greater

All of these divisions were arbitrary and made in advance of the data collection. It is possible that other groupings would be more significant. Tables 92 through 95 present the data for these analyses.

TABLE 92

NO. OF BENCHES VS PERFORMANCE

	Performance			
No of Benches	Very Good	Good	Marginal	Unsatisfactory
≤ 2	16	29	10	11
≥ 3	5	14	3	3
0	40	90	34	21

TABLE 93

NO. OF BENCHES VS CUT SLOPE AGE

No. of Benches	Cut Slope Age <5	5-15	>15
≤2	34	24	8
≥3	13	11	1
0	46	56	83

TABLE 94

BENCH HEIGHT VS PERFORMANCE

Bench Height	Performance Very Good	Good	Marginal	Unsatisfactory
≤49	13	29	1	8
≥50	8	14	12	6

TABLE 95

BENCH HEIGHT VS CUT SLOPE AGE

Bench Height	Cut Slope Age <5	5-15	>15
≤49	31	18	2
≥50	16	17	7

*The use of benches is most common on the younger cuts. This is a reflection of trends in design philosophy. Analysis of the benefits derived from such trends is strongly recommended.

*Marginal performance evaluations were received by a disproportionately high percentage of cuts with higher differences in bench elevations.

*Trends in bench spacings with age were also detected.

Failures

The categories of Failures included in this study are: Erosion, Ravelling, Rockfall, Surface Slides, Deep Slides, Other and None. Tables 96 and 97 present the data for the following analyses.

TABLE 96

FAILURES VS PERFORMANCE

	Performance			
Failures	Very Good	Good	Marginal	Unsatisfactory
Erosion	14	29	12	8
Ravelling	30	71	19	5
Rockfall	9	39	13	17
Surface Slide	3	17	14	14
Deep Slide	0	0	1	2
Other	5	11	12	5
None	12	8	0	0

TABLE 97

FAILURES VS CUT SLOPE AGE

	Cut Slope Age		
Failures	<5	5-15	>15
Erosion	16	26	21
Ravelling	41	39	45
Rockfall	23	25	30
Surface Slide	22	18	8
Deep Slide	0	2	1
Other	2	8	23
None	9	7	4

*Rockfall and Surface Slides are the predominant failures on Unsatisfactory cut slopes. Ravelling is primarily found on slopes classified as Good and Very Good in performance. The focusing of one or two types of problems on cuts with a given performance is recommended for further investigation.

*Surface Slides appear to be concentrated on young cut slopes while "Others" appear to occur on old slopes.

Performance

Four categories of performance were used in this study: Very Good, Good, Marginal, and Unsatisfactory. These groupings are arbitrary and not clearly defined. Different people made the evaluations and differing evaluations undoubtedly occurred as a result. Table 98 contains the data used in this comparison.

TABLE 98

PERFORMANCE VS CUT SLOPE AGE

Performance	Cut Slope Age <5	5-15	>15
Very Good	23	19	19
Good	36	55	42
Marginal	16	9	22
Unsatisfactory	18	8	9

*Most unsatisfactory cuts were young. This suggests current design practice should be investigated to assure its adequacy.

With the exception of Unsatisfactory, the anticipated trend of decreasing performance with increasing age was observed.

Geometric Relationships

The relationships between planar features of the geologic structure and the orientation of the cut slope were determined. The features included in this study were attitudes, joints, foliations and faults. The relationships were determined and grouped as shown in Table 99. These groupings were arbitrarily selected but were based in part on past experience and some theory from rock mechanics. Each of the groupings was then compared to some other factors to detect potentially useful relationships.

Tables 99 through 103 contain the data used in this study.

TABLE 99

ANGLE BETWEEN ℄ AND STRIKE OF STRUCTURE

VS

APPARENT DIP OF STRUCTURE

	Angle Between ℄ and Strike of Structure								
	<20			20-30			>30		
Apparent Dip of Structure	<30	30-40	>40	<30	30-40	>40	<30	30-40	>40
No. of Cuts	A_{17}	B_{18}	C_{100}	D_{9}	E_{6}	F_{64}	G_{100}	H_{41}	I_{159}

TABLE 100

TABLE 99 VS CUT SLOPE ANGLE

Table 99 Group No.	Cut Slope Angle $\geq$1/2:1	3/4:1	1:1	1 1/2:1	$\leq$2:1
A	5	4	4	2	2
B	3	9	2	4	0
C	35	33	22	10	0
D	5	2	2	0	0
E	1	1	3	1	0
F	23	19	15	7	0
G	27	35	24	11	3
H	16	10	12	3	0
I	55	55	44	5	0

TABLE 101

TABLE 99 VS CUT SLOPE HEIGHT

Table 99 Group No.	Cut Slope Height <40	40-80	81-120	>120
A	1	6	2	8
B	0	3	8	7
C	8	40	28	24
D	0	3	3	3
E	0	3	1	2
F	7	31	14	12
G	5	40	18	37
H	2	13	12	14
I	21	70	35	33

TABLE 102

TABLE 99 VS FAILURES

Table 99 Group No.	Failures: Erosion	Ravelling	Rockfall	Surface Slide	Deep Slide	Other	None
A	5	6	4	3	0	1	2
B	3	10	5	6	0	0	0
C	11	49	31	23	2	13	4
D	0	4	4	2	0	0	1
E	0	2	1	0	1	1	1
F	8	32	26	15	0	1	2
G	18	54	24	17	3	4	8
H	5	25	9	6	1	1	3
I	19	73	56	26	2	16	9

TABLE 103

TABLE 99 VS PERFORMANCE

Table 99 Group No.	Performance: Very Good	Good	Marginal	Unsatisfactory
A	4	8	3	2
B	6	7	3	2
C	12	55	17	16
D	3	4	0	2
E	0	3	1	2
F	9	37	7	11
G	19	55	17	9
H	21	7	8	5
I	26	87	29	17

*Before discussing these comparisons it should be stressed that, because of time and money limitations, the intersections of these planar features were not determined or studied. Experience has shown that such intersections are frequently the cause of unsatisfactory performance of cut slopes.

*The cut slopes with flatter angles appear to have been used in materials with flatter apparent dip angles. Further study of this observation should yield information directly applicable to cut slope design techniques.

*For the failure groups used in this project, it appears that high angles to centerline and high apparent dip angles both are significant factors.

*There is some indication that the cut slopes in materials with intermediate angles to ℄ and with intermediate apparent dip angles receive lower performance evaluations than the other groups.

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R. P. Miller and D. E. Hilts, "Experimental Open-Pit Mine Slope Stability Study", Eleventh Symposium on Rock Mechanics, June 1969.

R. G. Nutting and K. D. Weaver, "Slope Failure in Fissured Clay, Butte County, California", Seventh Annual Meeting of the Association of Engineering Geologists, 1964.

C. O. Brawner, "Three Big Factors in Stable Slope Design", Mining Engineering, Aug. 1969.

P. Loude, G. Vigier and R. Vormeringer, "Stability of Rock Slopes - Graphical Methods", Journal of the Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers, Jul. 1970.

D. S. Gedney, "Maintenance and Safety of Rock Cut Slopes", Highway Focus, Vol. 2 No. 5, Dec. 1970.

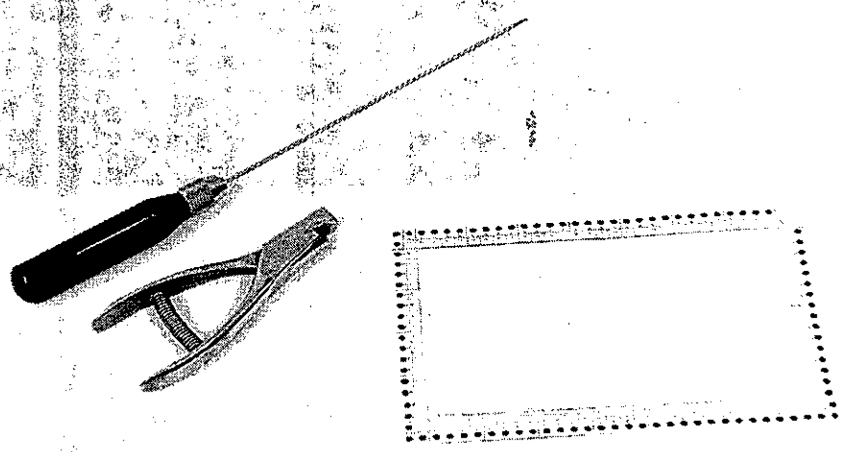
C. B. Beaty, "The Effect of Moisture on Slope Stability: A Classic Example from Southern Alberta, Canada", The Journal of Geology, Vol. 80, No. 3, May 1972.

J. D. Cadman, "The Origin of Exfoliation Joints in Granitic Rocks", Doctoral Dissertation, University of California, Berkeley, 1970.

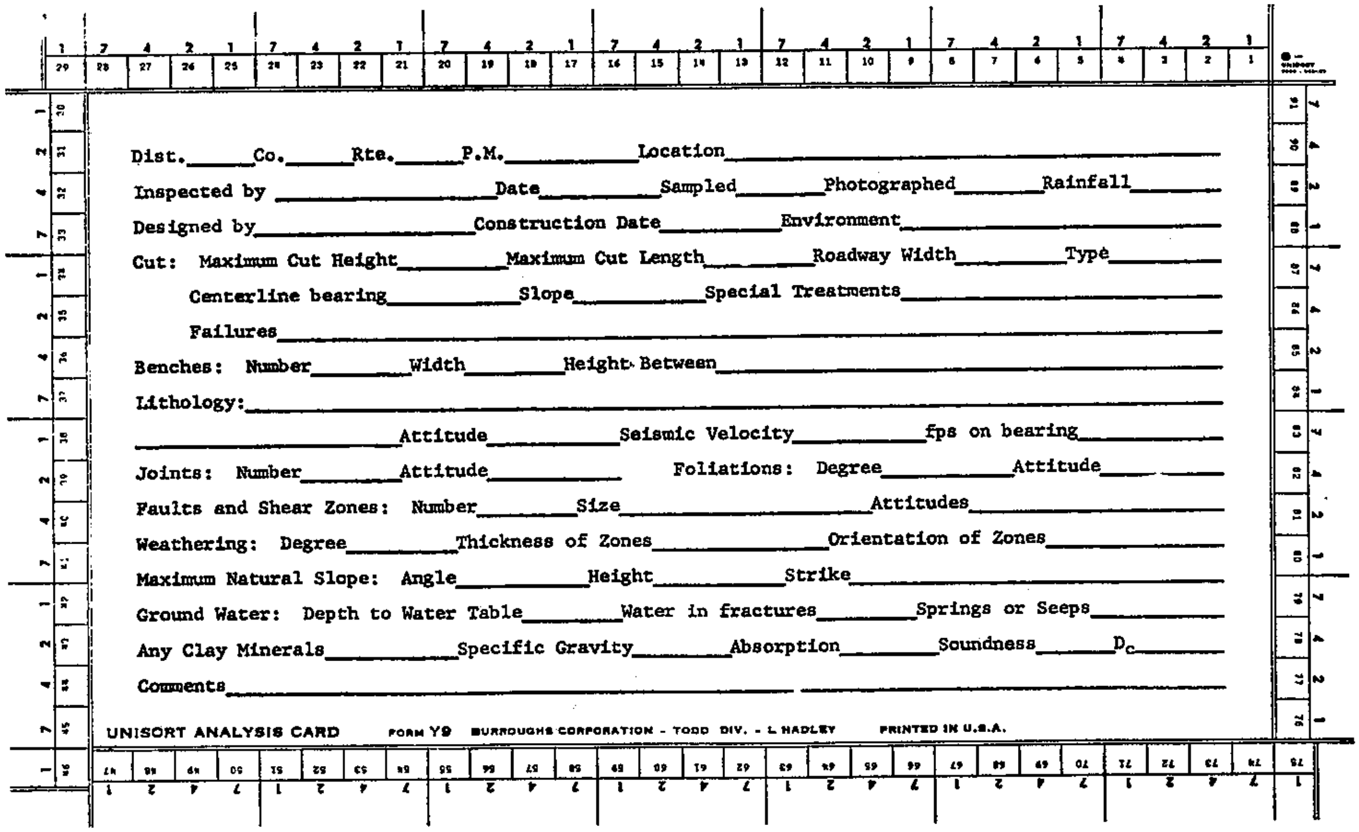
APPENDIX A

Data Retrieval System

The data storage and retrieval system employed in this study was the Burroughs Corporation Unisort System. This system consists of 5 X 8 inch cards with 95 numbered holes around the edge. Data is recorded on the card and keyed to the holes which are then notched out. For data retrieval, a sorting needle is inserted into the hole keyed to the desired data and those cards which drop out of the card file are the ones desired. A blank card, the notching tool and a sorting needle are pictured below.



What data to gather for each cut included in this study was decided upon by the Engineering Geology staff. An appropriate form was then developed and imprinted on the front of the data analysis card. The type of data to be gathered and the layout of the card can be seen in the following photograph.



Dist.______Co.______Rte.______P.M.__________Location

Inspected by __________Date__________Sampled__________Photographed__________Rainfall__________

Designed by__________Construction Date__________Environment__________

Cut: Maximum Cut Height__________Maximum Cut Length__________Roadway Width__________Type__________

Centerline bearing__________Slope__________Special Treatments__________

Failures__________

Benches: Number__________Width__________Height Between__________

Lithology:__________

__________Attitude__________Seismic Velocity__________fps on bearing__________

Joints: Number__________Attitude__________ Foliations: Degree__________Attitude__________

Faults and Shear Zones: Number__________Size__________Attitudes__________

Weathering: Degree__________Thickness of Zones__________Orientation of Zones__________

Maximum Natural Slope: Angle__________Height__________Strike__________

Ground Water: Depth to Water Table__________Water in fractures__________Springs or Seeps__________

Any Clay Minerals__________Specific Gravity__________Absorption__________Soundness__________D_c__________

Comments__________

UNISORT ANALYSIS CARD FORM Y9 BURROUGHS CORPORATION - TODD DIV. - L HADLEY PRINTED IN U.S.A.

The data collected for each cut slope inspected can be divided into three categories: Locators; Descriptors; and Design Variables. The following table lists the items included under each category.

LOCATORS

District
County
Route
Post Mile
Geographic Location

DESCRIPTORS

Cut Slope Type
Angle
Height
Length
Bearing

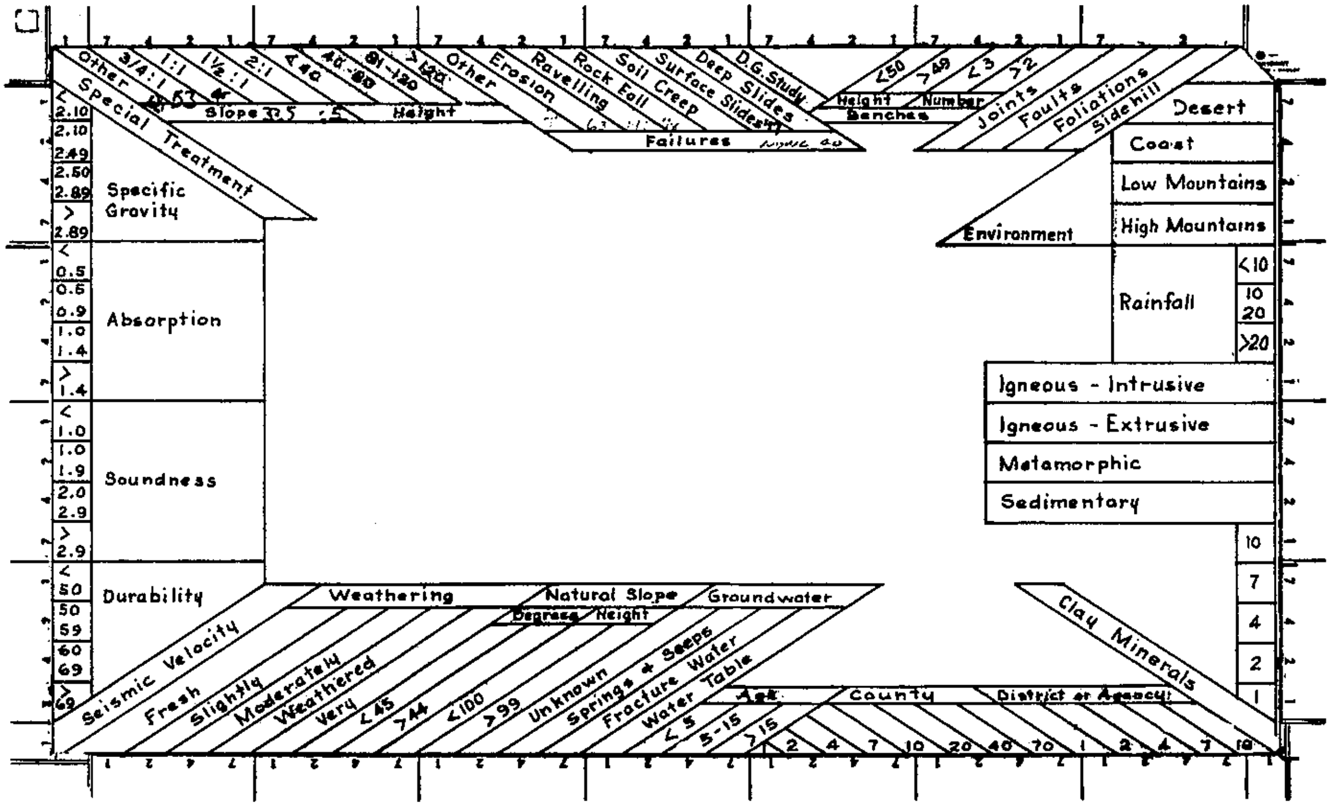
Bench Number
Width
Height
Roadway Width
Designer
Construction Date
Inspector
Inspection Data
Special Treatments
Failures
Performance Evaluation

DESIGN VARIABLES

Rainfall
Environment
Lithology
Seismic Data
Joints
Foliations
Faults
Weathering
Natural Slopes
Groundwater Data
Clay

Because of space limitations it was frequently necessary to write on the back of the card. The back was also used for sketching those conditions that could not be clearly described on the front.

To facilitate the data retrieval an index card was developed. This card had the edge holes identified and could be placed in front of the card file to readily indicate the hole into which the needle should be inserted to retrieve the desired data. The index card is shown as follows:



Because the number of hole spaces was limited, it was necessary to use number codes to retrieve Design Agency, County or Rock Type. Retrieval of number coded data is accomplished by consecutively retrieving the numbers required to total the desired number. The digits required to utilize such a number coding are imprinted on the basic card and only include 1, 2, 4 and 7 to obtain any number from 1 through 9. A second series of these digits can be used to obtain any number from 10 through 99.

The following table defines the number code used to describe the agency that designed the cut described on the card.

Code Number	Design Agency
1	Department of Transportation District 01
2	" " " " 02
3	" " " " 03
4	" " " " 04
5	" " " " 05
6	" " " " 06
7	" " " " 07
8	" " " " 08
9	" " " " 09
10	" " " " 10
11	" " " " 11
12	All Others

The county in which the cut is located was number coded as indicated in this table.

1. Alameda
2. Alpine
3. Amador
4. Butte
5. Calaveras
6. Colusa
7. Contra Costa
8. Del Norte
9. El Dorado
10. Fresno
11. Glenn
12. Humboldt
13. Imperial
14. Inyo
15. Kern
16. Kings
17. Lake
18. Lassen
19. Los Angeles
20. Madera
21. Marin
22. Mariposa
23. Mendocino
24. Merced
25. Modoc
26. Mono
27. Monterey
28. Napa
29. Nevada
30. Orange
31. Placer
32. Plumas
33. Riverside
34. Sacramento
35. San Benito
36. San Bernardino
37. San Diego
38. San Francisco
39. San Joaquin
40. San Luis Obispo
41. San Mateo
42. Santa Barbara
43. Santa Clara
44. Santa Cruz
45. Shasta
46. Sierra
47. Siskiyou
48. Solano
49. Sonoma
50. Stanislaus
51. Sutter
52. Tehama
53. Trinity
54. Tulare
55. Tuolomne
56. Ventura
57. Yolo
58. Yuba

Rock types were number coded as shown in this table.

Igneous Intrusive
1. Granite
2. Diorite
3. Gabbro
4. Ultrabasic
5. Diabase
6. Other

Igneous Extrusive
1. Rhyolite
2. Dacite
3. Tuff
4. Andesite
5. Basalt
6. Other

Metamorphic
1. Schist
2. Gneiss
3. Serpentine
4. Greenstone
5. Quartzite
6. Meta sandstone
7. Metavolcanic
8. Metagranitic
9. Metadiorite
10. Basic Metaigneous
11. Other

Sedimentary
1. Sandstone
2. Sandstone fossiliferous
3. Siltstone
4. Conglomerate
5. Limestone
6. Dolomite
7. Chert or cherty
8. Other

Since the number coding systems were set up in advance of data collection, they do contain some holes that were never used.

This type of data retrieval system is simple and inexpensive to set up but as has been mentioned it is limited as to how much data can be stored and retrieved. It also has the disadvantage requiring a committment to the retrievable data before any analysis has been completed. This feature means that to change the data retrieval groupings it is necessary to copy the data and re-notch the cards. This is time consuming and therefore expensive.

Two types of purely mechanical problems appear to be inherent with this system. Preparing and notching the cards is slow, tiring work and although several people were involved, numerous mistakes were made. The discovery of mistakes made a complete check of all data retrieval holes necessary. As a result of this check nearly a third of the cards had to be redone. The second problem is with too many cards in the file, the desired cards do not drop freely from the needle. Thus, when using more than about 100 cards, it was necessary to check carefully to assure that all the notched cards had dropped.

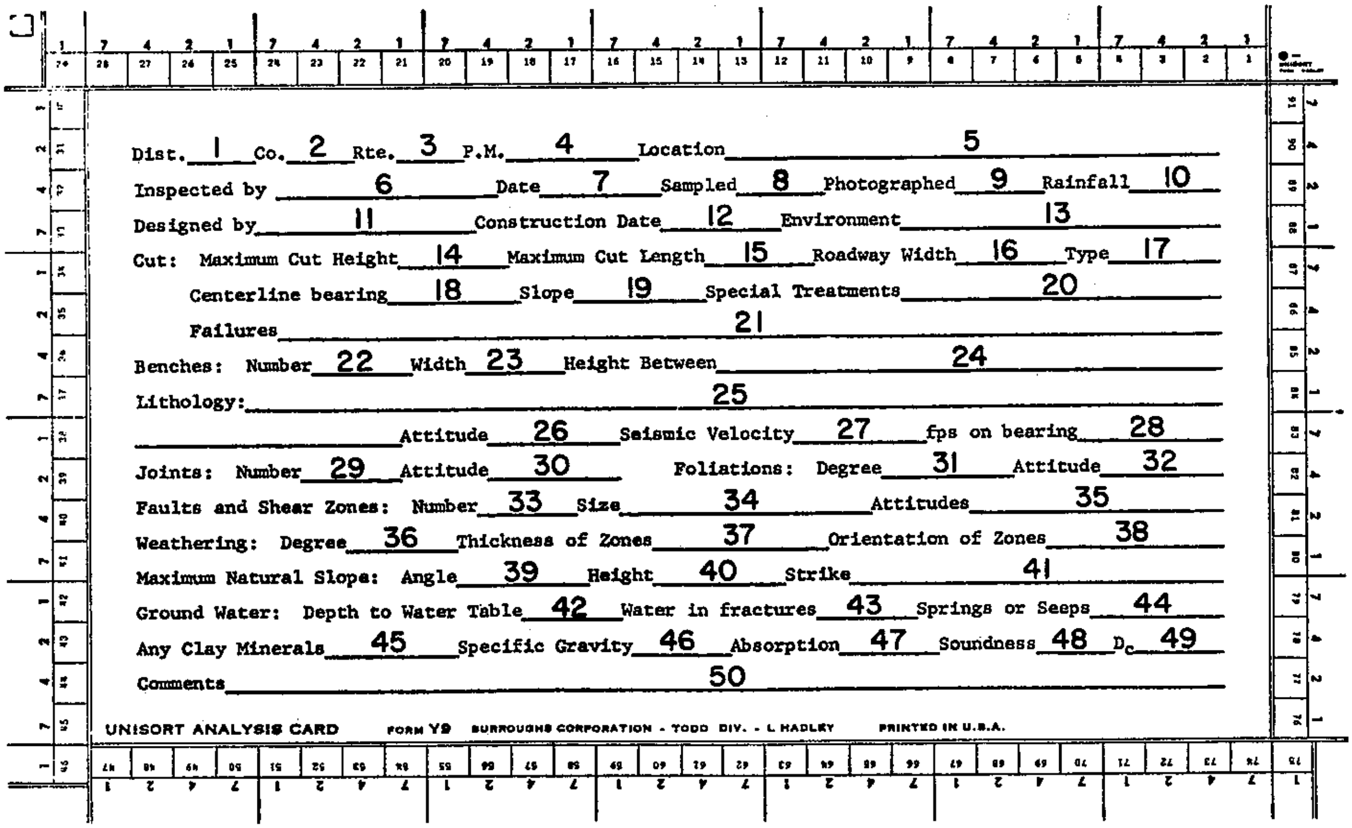
Although this project was completed with the Unisort system described above, it will probably not be used again. There are numerous punched card systems with much higher data capacity and which are easier to use.

APPENDIX B

Data Collection

The data stored in the retrieval system described in Appendix A was obtained by personnel of the Engineering Geology unit of California Division of Highways, Transportation Laboratory. These geologists made detailed field and office studies in compiling the data.

To facilitate analysis, detailed procedures for recording the data were followed. These procedures discussed all of the information that was required and provided certain key words so that comparisons between individual cards could be made independently of the cut slope inspector.



Dist. 1 Co. 2 Rte. 3 P.M. 4 Location 5
Inspected by 6 Date 7 Sampled 8 Photographed 9 Rainfall 10
Designed by 11 Construction Date 12 Environment 13
Cut: Maximum Cut Height 14 Maximum Cut Length 15 Roadway Width 16 Type 17
Centerline bearing 18 Slope 19 Special Treatments 20
Failures 21
Benches: Number 22 Width 23 Height Between 24
Lithology: 25
Attitude 26 Seismic Velocity 27 fps on bearing 28
Joints: Number 29 Attitude 30 Foliations: Degree 31 Attitude 32
Faults and Shear Zones: Number 33 Size 34 Attitudes 35
Weathering: Degree 36 Thickness of Zones 37 Orientation of Zones 38
Maximum Natural Slope: Angle 39 Height 40 Strike 41
Ground Water: Depth to Water Table 42 Water in fractures 43 Springs or Seeps 44
Any Clay Minerals 45 Specific Gravity 46 Absorption 47 Soundness 48 D_c 49
Comments 50
UNISORT ANALYSIS CARD FORM Y9 BURROUGHS CORPORATION - TODD DIV. - L HADLEY PRINTED IN U.S.A.

The above sample data card has all the blanks number coded. The numbers are repeated below with appropriate directions for properly recording the desired data.

1. Transportation District in which cut is located.

2. County in which cut is located.

3. State highway route on which cut is located, if applicable.

4. Post Mile if applicable.

5. A short geographic description of the location of the cut, particularly if it is not on a State highway.

6. Name of person or persons filling out the data card.

7. Date of field inspection.

8. Indicate number of samples that were taken.

9. Indicate number of photographs that were taken.

10. Approximate average annual rainfall based on nearest U.S. Weather Bureau Reporting Station.

11. Name of agency responsible for construction of the cut.

12. Year that cut was completed.

13. Use whichever of the following terms apply:

Desert	- Colorado or Mojave Desert Geomorphic provinces.
Coast	- Within 8 miles of the ocean.
For all areas not in "Coast" or "Desert"	
Low Mountains	- Less than 3000 feet in elevation
High Mountains	- More than 3000 feet in elevation

14. Difference in elevation between grade and highest point on cut slope.

15. Distance from beginning to end of cut.

16. Width of paved roadway.

17. Through or sidehill.

18. True bearing of center line.

19. Vertical angle between horizontal and cut slope.

20. Special treatments include such things as, but not limited to: horizontal drains, underdrains, plantings, etc.

21. Failures including, but not limited to: deep slides, surface slides, soil creep, rockfall, raveling, and erosion.

22. Number of benches.

23. Width of benches.

24. Vertical difference in elevation between benches.

25. Lithology - includes, but not limited to: rock type, mineralogy, structure.

26. Strike and dip, if applicable.

27. Refracted seismic velocity, if known.

28. True bearing of seismic line from which the refracted seismic velocity was determined.

29. Number of sets of joints.

30. Strike and dip of each joint set, if applicable.

31. Degree of development of foliations.

32. Strike and dip of foliation, if applicable.

33. Number of faults and shear zones.

34. Size of faults and shear zones.

35. Strike and dip of faults and shear zones, if applicable.

36. Degree of weathering: fresh; slightly weathered; moderately weathered; weathered; very weathered.

37. Thickness of weathered zones.

38. Attitude of weathered zone contact.

39. Maximum vertical angle between horizontal and natural slope in similar material.

40. Height of the natural slope on which the angle was measured.

41. Strike of the natural slope (true bearing).

42. Depth to water table, if known.

43. Indicate if fracture water is present.

44. Indicate the presence of springs or seeps.

45. Indicate the presence of clay minerals in the cut and identify, if possible.

46. Test result, if known.

47. Test result, if known.

48. Test result, if known.

49. Test result, if known.

50. Any relevant comment and a performance evaluation using the following terms:

    Very good.
    Good.
    Marginal.
    Unsatisfactory.

    For complex cuts, a sketch may be included on the back of card.

The data collection was accomplished between Feb. 1967 and Jan. 1970. The cuts included in this study were selected because of previous knowledge or after discussions with District personnel. The main considerations were the necessity of a single rock type in each cut, a variety of rock types in the study and a wide geographic distribution. Using these criteria, a total of 276 cut slopes were selected and inspected. This process was carried out with no significant difficulties.

Dist. 01 Co. DN Rte. 199 P.M. 20.70 Location Smith River - 1mi S. of Patricks Creek

Inspected by Love Date 9-4-69 Sampled Yes Photographed / Rainfall 94"

Designed by BPR (?) Construction Date 1925± Environment Low Mountains

Cut: Maximum Cut Height 100' Maximum Cut Length 1000' Roadway Width 27' Type Sidehill

Centerline bearing N75W Slope 65° (½:1) Special Treatments None

Failures Surface popouts

Benches: Number None Width ____ Height Between ____

Lithology: Serpentinized ultrabasic - highly broken with talc in fractures Attitude — Seismic Velocity — fps on bearing —

Joints: Number 3 Attitude N50E 82SE, N36W 47N, N75W 70S Foliations: Degree Minor Attitude N35E

Faults and Shear Zones: Number None Size ____ Attitudes ____

Weathering: Degree W/F Thickness of Zones Uniform Orientation of Zones ∥ to joints & foliation

Rock fragments are fresh

Maximum Natural Slope: Angle 45° Height 200' Strike Various

Ground Water: Depth to Water Table ____ Water in fractures No Springs or Seeps No

Any Clay Minerals ____ Specific Gravity ____ Absorption ____ Soundness ____ D_c ____

Comments Unsatisfactory - oversteep for material because of talc in ground mass

UNISORT ANALYSIS CARD FORM Y9 BURROUGHS CORPORATION - TODD DIV. - L HADLEY PRINTED IN U.S.A.

The only problem encountered in using the system as described was the lack of information on which side of the road the geologic structure was determined. This information was absolutely essential to determine if geologic structure is related to the stability of the cut slope. It was necessary to determine, from the photographs or if necessary by returning to the cut, the relationship of geologic structure and roadway geometry.

In addition to its use in this research project, the card file has been useful in evaluating the performance of various designs in order to make recommendations for future projects.

Data developed on this project has also been used as background for initiating a research project covering slope design in intermediate quality rocks.

The report contained in Appendix C, as has been mentioned, also covers work which is based in part on data from this project.

In investigating certain aspects of the problem of erosion, the card file has been used to identify locations having certain desired conditions.

The data stored in this system thus has proven to be very useful in numerous ways not previously anticipated, and has added to the value of this research project.

APPENDIX C

Slope Design in Disintegrated Granite

State of California

Business and Transportation Agency

Memorandum

To : Mr. Travis Smith

Date: June 16, 1970

File : 19107-641139-38155

From : **Department of Public Works—Division of Highways**
Materials and Research Department

Subject: Slope Stability in Disintegrated Granitic Rocks

During several years of working with seismic data including follow up studies, it was noticed that in disintegrated granitic materials, the seismic velocity seemed to correlate with slope stability. While compiling data for a BPR-financed research study entitled "Design Variables for Cut Slopes" the same correlation seemed to be developing.

This report is a compilation of data from past jobs, the above mentioned research project and some data gathered just for this report. The object of the compilation is to determine if the correlation between the seismic velocity in disintegrated granitic rocks and slope stability is consistent enough to permit slope design based on seismic velocity.

For purposes of this report disintegrated granitic rock is defined as the weathering product formed by the disintegration of igneous intrusive rocks having a mineral composition ranging from granite to diorite. The mass of material is in place, may exhibit some relic structural features and the bond between crystals has been weakened or destroyed.

A total of 26 cuts are included in this study. The areal distribution of these cuts is shown on the attached map of California. There are some cuts in each of the main environments in which granitic rocks are found: coastal; high mountains; and desert. The exact locations of the cuts are included in Table 1 along with the type of rock encountered. Table 2 includes a number of physical characteristics which were considered important. Appendix A includes appropriate sketches of each cut area along with location of seismic lines and seismic line profiles.

FORM H-AD 37A

Weathering

The degree of weathering included in Table 2 is based on analysis of the X-ray diffraction records and microscopic inspection of the material by an experienced Engineering Geologist.

% Clay Minerals

The reported percentages of clay minerals represents the percentage of the sample that is made up of clay minerals as identified by X-ray diffraction techniques using standard calibrated powders as references.

Seismic Velocity

Seismic velocity is reported in feet per second and was obtained using an Electro-Tech ER-75-12 12-channel seismic timer with both hammer blows and explosives as energy sources. In those cases where two distinctively different velocities were detected both are reported.

Slope Angle and Height

These physical characteristics are included to aid in describing the cut.

Visual Evaluation

This is a subjective evaluation of the performance of the cut as constructed. The geologist inspecting each cut made this evaluation in the field.

Only two of the cuts studied were found unsatisfactory. The failures were the result of excessive ground water and low permeability resulting in excessive pore pressures. This lack of failures suggests that cut slopes in disintegrated granitic rocks often may be flatter than necessary. This study is intended to provide an objective basis for the design of such slopes.

The first analysis used the field data as gathered and did not provide useful design guidelines. A second trial at developing useful guidelines utilized the concept of "the steepest stable slope." Since factual information of this type was not available, a team of engineering geologists including the one responsible for the field inspection of the cut estimated the "steepest stable slope" based on their pooled knowledge and experience. Table 3 shows the steepest stable slope for each of the cuts included in this study.

The coefficient of correlation between the steepest stable slope and each of the three physical characteristics was computed using a linear regression analysis. In order to perform these computations weathering and slope designs were number coded as follows:

Very Weathered=1	Weathered=2	Moderately Weathered=3
1/4:1=1	1/2:1=2	3/4:1=3
1:1=4	1-1/2:1=5	2:1=6

The coefficients thus computed were:

Steepest	Stable	Slope	vs Seismic Velocity	= .42
"	"	"	vs % Clay Minerals	= .75
"	"	"	vs Weathering	= .62

These results are surprising in that the relationship to seismic velocity which started this research project is the poorest of those studied. Both weathering and percent of clay minerals are based essentially on the same information as interpreted by the same engineering geologist. Since % of clay minerals has a better correlation it was used instead of weathering. Data for these analyses are plotted in Figures 1, 2 and 3.

Analysis of the data gathered for this study yield the following guidelines for slope design in disintegrated granitic rocks.

1) Seismic velocity 1800 fps or greater

   1/2:1 or 1/4:1 for cuts less than 50'
   3/4:1 for cuts up to 100'

2) Seismic velocity less than 1800 fps

   3/4:1 for cuts less than 50'
   1:1 for cuts from 50' to 80'
   1-1/2:1 or flatter for cuts higher than 80'

3) Clay mineral content less than 10%

   1/2:1 for cuts less than 50'
   3/4:1 for cuts up to 100'

4) Clay mineral content greater than 10%

   3/4:1 for cuts less than 50'
   1:1 for cuts from 50' to 80'
   1-1/2:1 or flatter for cuts higher than 80'

R. Mearns

RM:kk

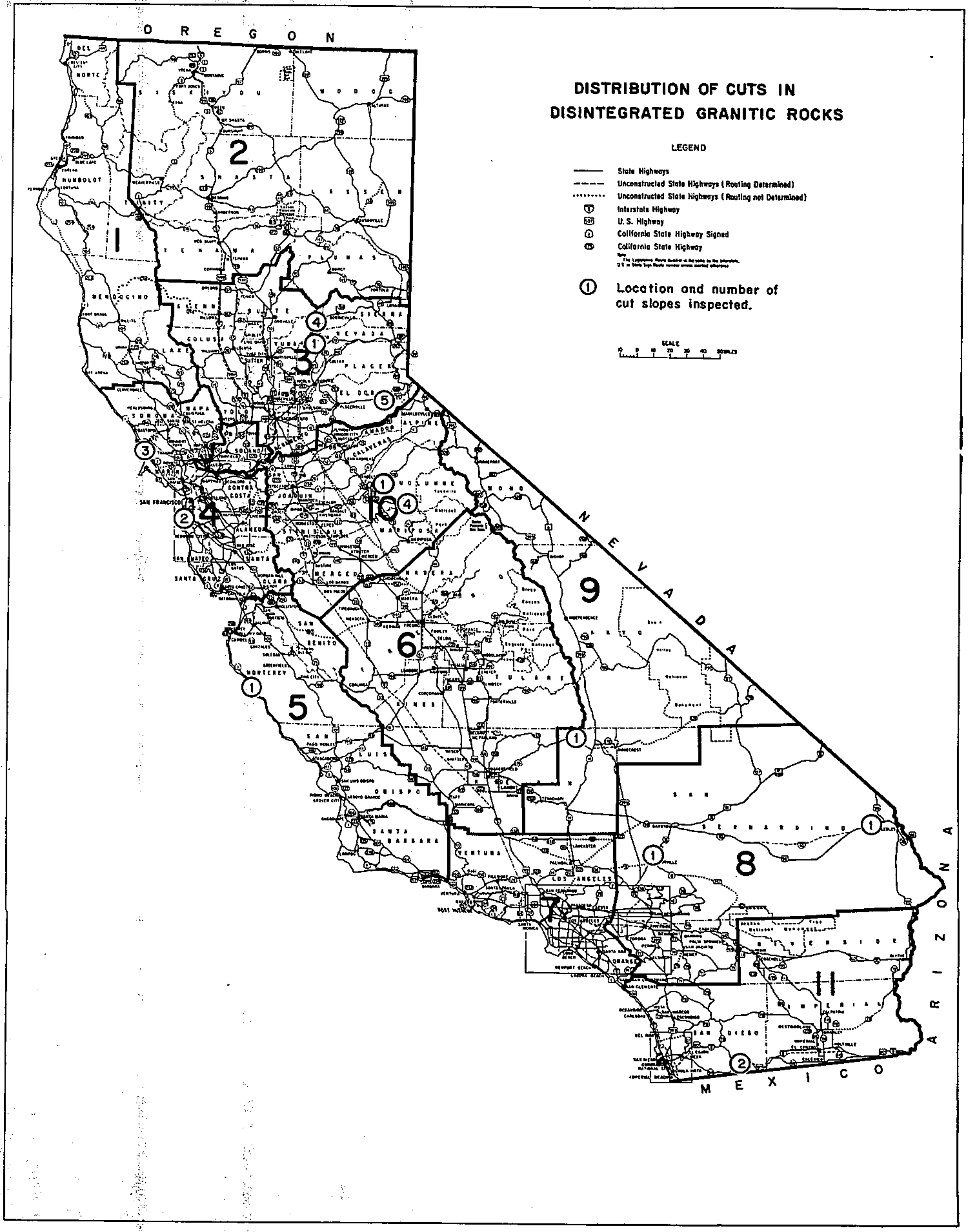

DISTRIBUTION OF CUTS IN
DISINTEGRATED GRANITIC ROCKS
LEGEND
State Highways
Unconstructed State Highways (Routing Determined)
Unconstructed State Highways (Routing not Determined)
Interstate Highway
U. S. Highway
California State Highway Signed
California State Highway
Location and number of
cut slopes inspected.
SCALE
O R E G O N
N E V A D A
A R I Z O N A
M E X I C O
SAN FRANCISCO
LOS ANGELES
MONTEREY

TABLE 1

Location and Rock Type for Cuts Included in this Study

Cut No.	Location	Rock Type
1	03-Nev-49 - 31.46	Quartz Monzonite
2	03-Yub-49 - 1.02	Quartz Diorite
3	03-Yub-49 - 2.63	" "
4	03-Yub-49 - 2.63	" "
5	03-Yub-49 - 3.02	" "
6	03-ED-50 - 46.79	" "
7	03-ED-50 - 46.84	Quartz Monzonite
8	03-ED-50 - 49.94	" "
9	03-ED-50 - 49.98	" "
10	03-ED-50 - 51.00	Granodiorite
11	04-Mrn-109 - 27.28	Quartz Monzonite
12	04-Mrn-109 - 27.58	" "
13	04-Mrn-109 - 27.59	" "
14	04-SM-1 - 37.195	Quartz Diorite
15	04-SM-1 - 37.54	" "
16	05-Mon-1 - 42.95	" "
17	08-SBd-15 - 55.75	Granodiorite
18	08-SBd-40 - 134.12	"
19	09-Ker-178 - 80.30	"
20	10-Tuo-108 - 11.45	Granite
21	10-Tuo-120 - 48.45	Quartz Monzonite
22	10-Tuo-120 - 48.65	Quartz Diorite
23	10-Tuo-120 - 51.70	" "
24	10-Tuo-120 - 54.64	" "
25	11-SD-8 - 56.72	" "
26	11-SD-8 - 61.50	Granodiorite

TABLE 2

Physical Characteristics of Cuts Included in this Study

Cut No.	Weathering*	% Clay	Seismic Velocity Ft/Second	Slope Angle	Slope Height	Slope Visual** Evaluation
1	W	10	1550	3/4:1	105	G
2	MW	5	1400	1:1	50	G
3	W	5	1900	3/4:1	78	G
4	MW	10	2150	1/4:1	65	G
5	W	Trace	1250	3/4:1	70	G
6	W	5-10	1600	1:1	38	G
7	W	10-20	1100-2200	3/4:1	54	M
8	W	10	1300-2400	1/2:1	43	M
9	W	Trace	1200	1/2:1	50	G
10	VW	10	1200	1/2:1	48	G
11	W	5-10	1400-2800	1/2:1	30	G
12	W	5	1450	1/2:1	35	G
13	W	5	1550	1/4:1	35	M
14	W	5	2050	3/4:1	48	G
15	W	5	2500	3/4:1	72	G
16	W	25-35	2200	3/4:1	90	G
17	MW	0	2900	2:1	28	G
18	MW	15-20	3350	3/4:1	23	G
19	MW	20-25	2600	1:1	8	G
20	VW	35	1200	1½:1	48	G
21	VW	30-45	1350	1½:1	80	U
22	VW	25-30	1750	1½:1	90	G
23	VW	15-20	1600	1½:1	25	M
24	VW	10-15	1000-1450	1½:1	75	U
25	MW	0	3100	1/2:1	50	G
26	MW	0	3150	1½:1	60	G

*VW - Very Weathered
W - Weathered
MW - Moderately Weathered

**G - Good
M - Marginal
U - Unsatisfactory

TABLE 3

Estimated Steepest Stable Slope
For Cuts Included in this Study

Cut No.	Slope
1	1/2:1
2	3/4:1
3	3/4:1
4	1/4:1
5	3/4:1
6	3/4:1
7	3/4:1
8	1/2:1
9	1/2:1
10	1/2:1
11	1/4:1
12	1/2:1
13	1/2:1
14	1/2:1
15	3/4:1
16	3/4:1
17	1/4:1
18	3/4:1
19	3/4:1
20	1:1
21	2:1
22	1½:1
23	1:1
24	1:1
25	1/4:1
26	1/2:1

RELATIONSHIP BETWEEN STEEPEST STABLE SLOPE AND SEISMIC VELOCITY

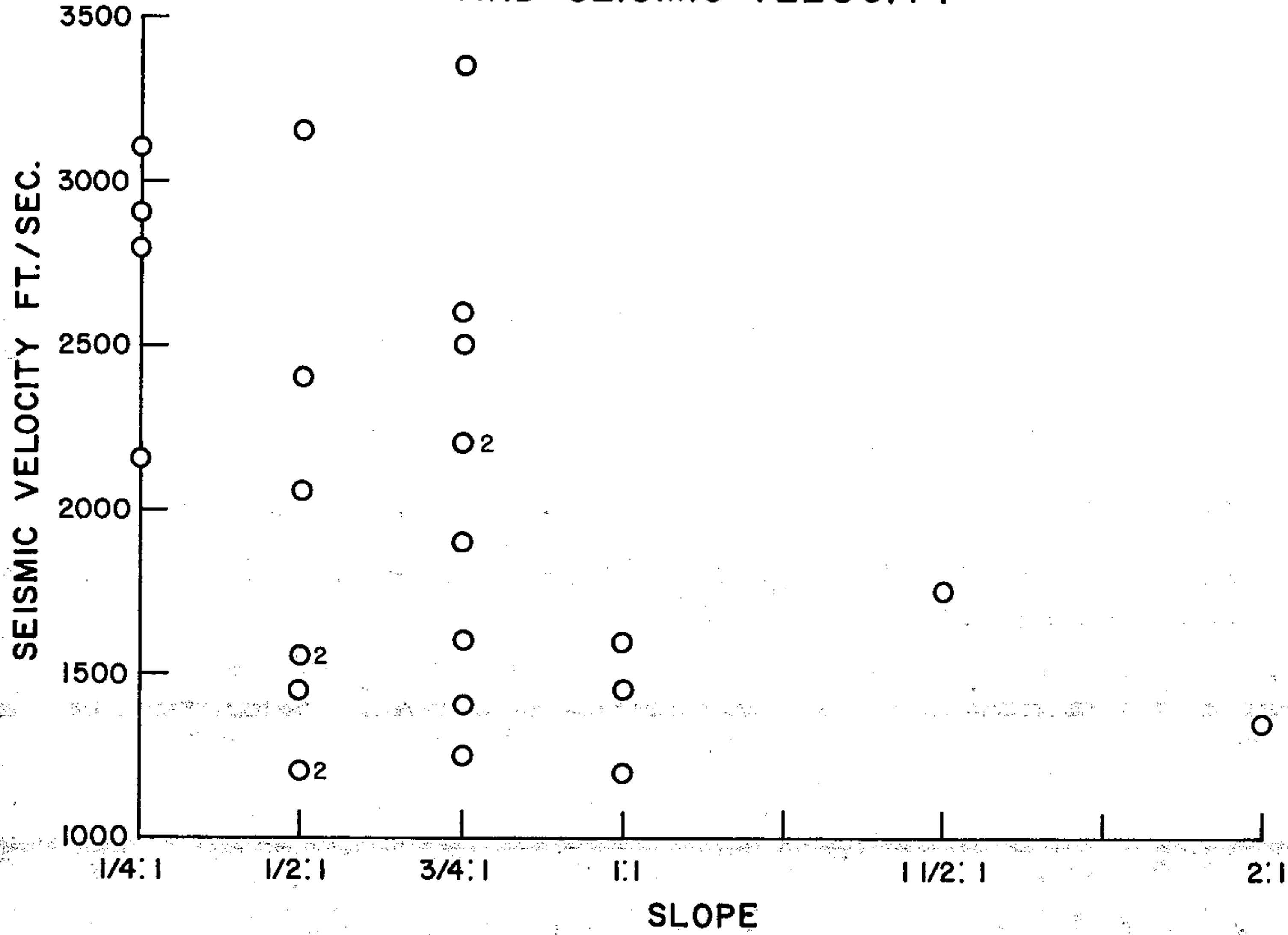


Figure 1

RELATIONSHIP BETWEEN STEEPEST STABLE SLOPE AND % CLAY

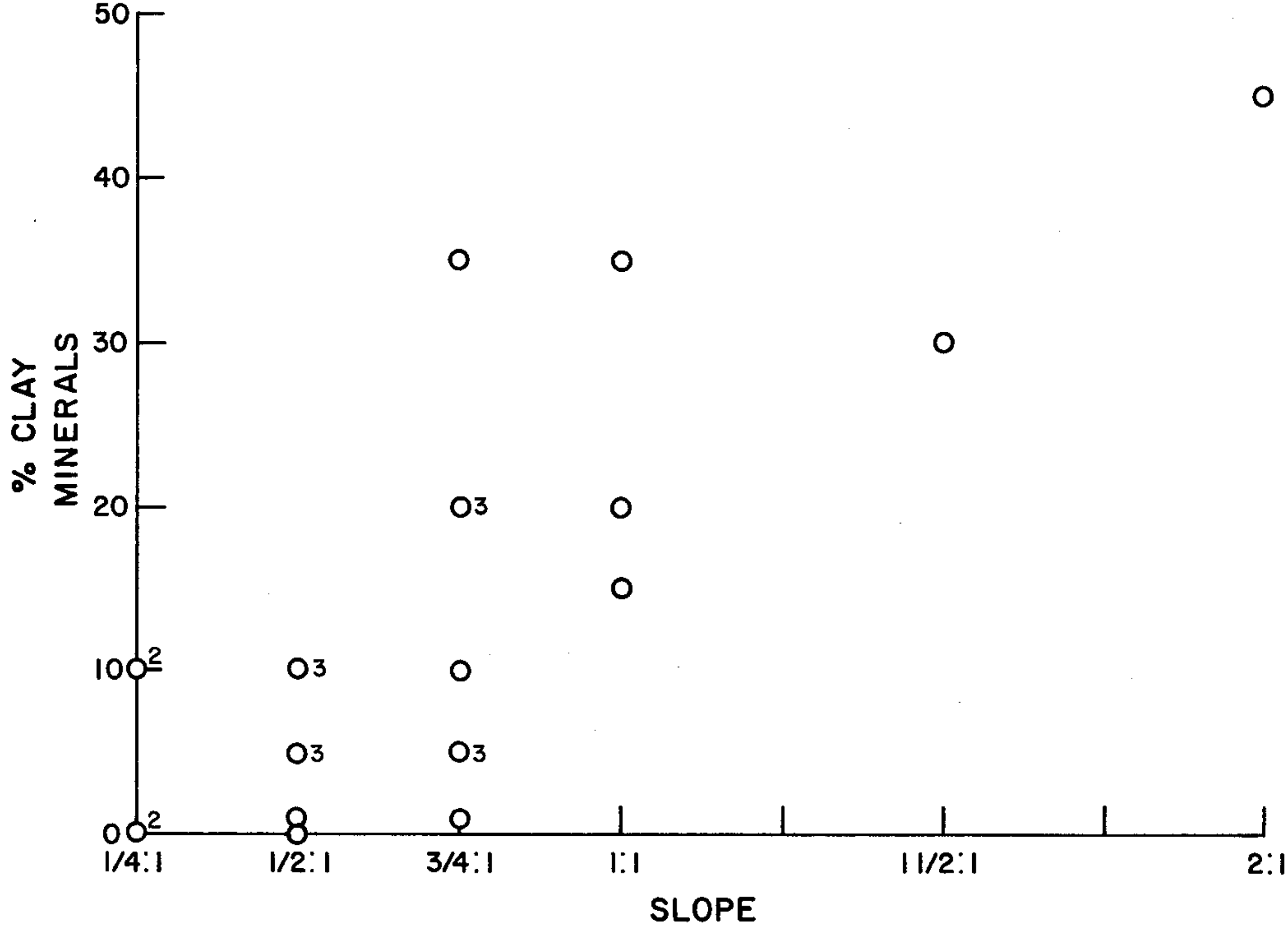


Figure 2

Figure 3

RELATIONSHIP BETWEEN STEEPEST STABLE SLOPE AND DEGREE OF WEATHERING